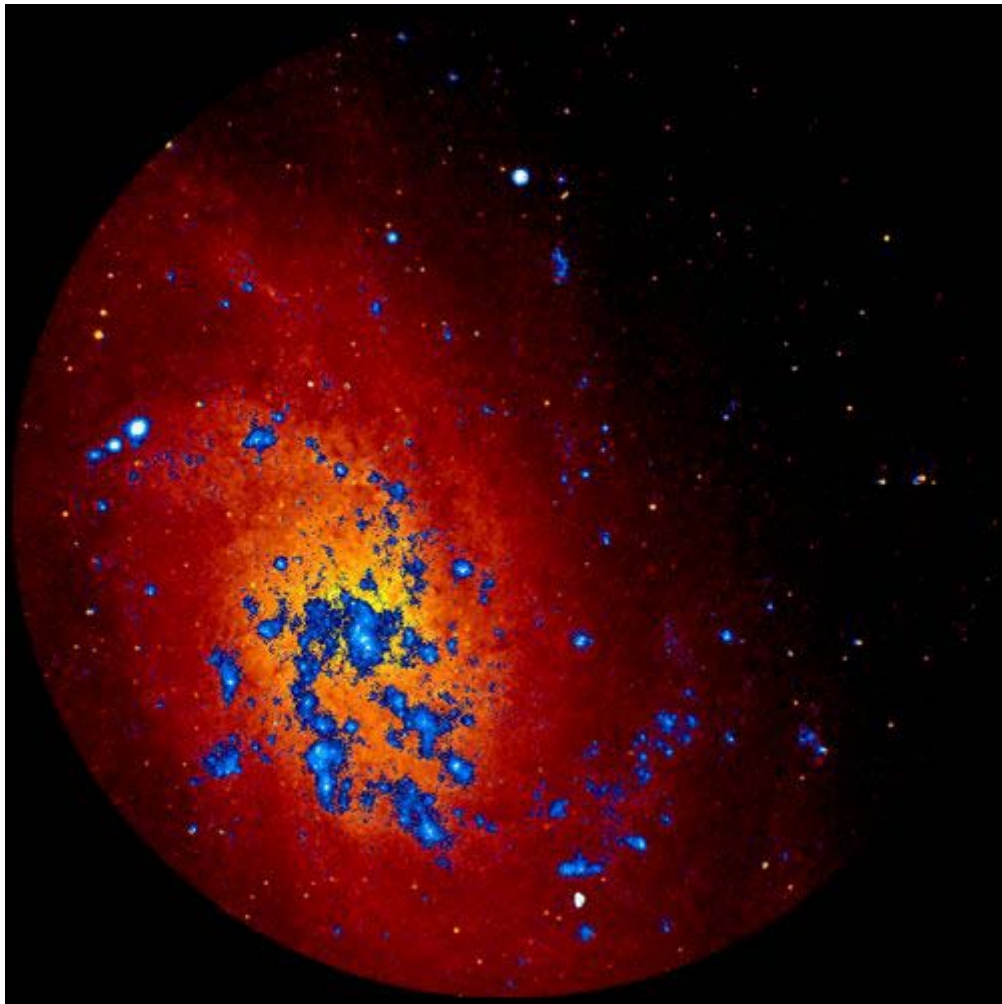


Unsolved Mystery of Molecules Found in Andromeda & Triangulum Galaxies

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In the summer of 2011, a team of NASA and European scientists recorded the "fingerprints" of mystery molecules in two distant galaxies, Andromeda and the Triangulum (image above). Astronomers can count on one hand the number of galaxies examined so far for such fingerprints, which are thought to

belong to large organic molecules (molecules that have at least 20 atoms or more), according to the team's leader, Martin Cordiner of NASA's Goddard Center for Astrobiology. This is quite small compared to, say, a protein, but huge compared to a molecule of carbon monoxide, a very common molecule in space.

Figuring out exactly which molecules are leaving these clues, known as "diffuse interstellar bands" (DIBs), is a puzzle that initially seemed straightforward but has gone unsolved for nearly a hundred years. The answer is expected to help explain how stars, planets and life form, so settling the matter is as important to astronomers who specialize in chemistry and biology as determining the nature of dark matter is to the specialists in physics. The findings provide some evidence against one of the top candidates on the list of suspects: polycyclic aromatic hydrocarbons (PAHs), a group of molecules that is widespread in space. The research also reveals that some of the signatures found in Andromeda and the Triangulum are similar to ones seen in our own Milky Way, despite some big differences between those galaxies and ours.

"We have studied DIBs in incredibly diverse environments. Some have low levels of UV radiation. Some have radiation levels thousands of times higher. Some have different amounts of 'ingredients' available for making stars and planets," Cordiner said. "And throughout all of these, we see DIBs."

Until now, only two galaxies beyond our own have been investigated in detail for DIBs. Those are our nearest neighbors, the Large and Small Magellanic Clouds, which lie 160,000 to 200,000 light years away. Andromeda and the Triangulum are located much farther away, at about 2.5 to 3 million light years from Earth. "At those distances, individual stars are so faint that we need to push even the largest telescopes in the world to their limits in order to observe them," Cordiner said.

To effectively study DIBs, researchers have to pick out individual stars within the galaxy, and only a few telescopes worldwide are powerful enough to gather

sufficient light for that, which is why most DIBs found so far have been in the Milky Way. (The team used the Gemini Observatory's telescope in Hawaii.)

"The first step is choosing which stars to observe," Cordiner explained.

Cordiner's colleagues at Queen's University in Belfast, U.K., took the lead on finding good targets. They picked blue supergiants—stars that are very large, very hot and very bright. Supergiants also burn very clean: unlike our sun and other cooler stars, they contribute little background clutter to the observations being made.

In the image below, The Triangulum Galaxy, located nearly 3 million light years from Earth, researchers have found diffuse interstellar bands (DIBs). The detailed observations needed to see DIBs along a straight line from Earth to an individual star in such a distant galaxy stretch the limits of even the largest telescopes.

To look for DIBs, an astronomer points the telescope at a star and scans through a rainbow made up of thousands of wavelengths of light. This rainbow, or spectrum, is extended a bit beyond visible light, into the UV at the blue end and into the infrared at the red end.

DIBs are not defined by what astronomers see while doing this, but by what they don't see. The colors missing from the rainbow, marked by black stripes, are the ones of interest. Each one is a wavelength being absorbed by some kind of atom or molecule.

A DIB is one of these regions where the color is missing. But compared to the nice, neat "absorption lines" that are identified with atoms or simple molecules, a DIB is not well-behaved, which is why it stands out.

"Astronomers were used to seeing quite sharp, narrow bands where typical atoms and molecules absorb," said Cordiner. "But DIBs are broad; that's why they are called 'diffuse.' Some DIBs have simple shapes and are quite smooth, but others have bumps and wiggles and may even be lopsided."

Over time, astronomers have been building up catalogs to show exactly which wavelengths are absorbed by all kinds of atoms and molecules. Each molecule has its own unique pattern, which can be used like a fingerprint: if a pattern found during an astronomical observation matches a pattern in one of the catalogs, the molecule can be identified.

It's a pretty straightforward concept. So, early researchers "would surely not have thought that the solution to the diffuse band problem would still be so elusive," wrote Peter Sarre in a 2006 review article about DIBs. Sarre, a professor of chemistry and molecular astrophysics at the University of Nottingham, U.K., supervised Cordiner's graduate-school work on DIBs.

The significance of the first DIBs, recorded in 1922 in Mary Lea Heger's Ph.D. thesis, was not immediately recognized. But once astronomers began systematic studies, starting with a 1934 paper by P. W. Merrill, they had every reason to believe the problem could be solved within a decade or two. More than 400 DIBs have been documented since then. But not one has been identified with enough certainty for astronomers to consider its case closed.

"With this many diffuse bands, you'd think we astronomers would have enough clues to solve this problem," observed Joseph Nuth, a senior scientist with the Goddard Center for Astrobiology who was not involved in this work. "Instead, it's getting more mysterious as more data is gathered." Detailed analyses of the bumps and wiggles of the DIBs, suggest that the molecules which give rise to DIBs—called "carriers"—are probably large. Recently, more interest has been focused on at least one small molecule, a chain made from three carbon atoms and two hydrogen atoms (C_3H_2). This was tentatively identified with a pattern of DIBs.

On the list of DIB-related suspects, all molecules have one thing in common: they are organic, which means they are built largely from carbon. Carbon is great for building large numbers of molecules because it is available almost everywhere. In space, only hydrogen, helium and oxygen are more

plentiful. Here on Earth, we find carbon in the planet's crust, the oceans, the atmosphere and all forms of life.

Astronomers "see DIBs pretty much in any direction we look," says Jan Cami, an astronomer at the University of Western Ontario, Canada. He has collaborated with Cordiner before but was not involved in this study. "And we see lots of DIBs."

Carbon is also great for building molecules in all kinds of configurations—millions of carbon compounds have been identified—and especially for building very stable molecules.

DIB carriers also seem to be quite stable. They survive the harsh physical conditions in the interstellar medium—the material found in the space between the stars. They also hang tough in the Large Magellanic Cloud, where radiation levels are thousands of times stronger than in the Milky Way. In fact, says Cordiner, DIB carriers seem comfortable almost everywhere except in the clouds of dense gas where stars are born.

"The carriers are readily formed but not readily destroyed in a wide range of different environments," says Cordiner. "It's remarkable how tenacious these molecules really are."

In short, carriers are thought to be made of carbon, Cami says, "because it's a lot easier to build strong and stable molecules from carbon atoms than from other elements, such as silicon or sulfur. Using those elements rather than carbon would be like building a house from a bucket of sand while there's a huge pile of bricks at the construction site."

The top three carrier candidates are: chain-like molecules, like the one now tentatively associated with a pattern of DIBs; PAHs, which often come up in studies of how planets formed; and compounds related to fullerenes, the soccer-ball-shaped molecules also known as buckyballs.

"This list covers most types of carbon molecules," notes Cami. "Chains are essentially the one-dimensional carbon molecules, PAHs are the two-dimensional ones, and fullerene compounds are the three-dimensional ones."

In spite of the challenges of looking for DIBs in other galaxies, it's worth the effort to astronomers because they need to see what DIBs look like under different conditions.

"But being on Earth and looking at another object in the Milky Way is like being in the crowd at Times Square in New York City on New Year's Eve and trying to find your friend," explains Nuth.

"It's much easier to spot the person if you are on a balcony rather than standing in the crowd yourself." Likewise, it's much easier to get a clear overview of a galaxy when you are outside of it.

In some respects, Andromeda and the Triangulum are similar to the Milky Way. All three are spiral galaxies that belong to a collection of more than 30 nearby galaxies called the Local Group. The Milky Way is the largest member of this group. Andromeda is the second-largest, and the Triangulum is third. Like the Milky Way, Andromeda and the Triangulum are thought to be good places to synthesize large organic molecules, which is what DIBs carriers are thought to be. And yet, says Cordiner, "nobody knew until now whether DIBs actually existed in either galaxy."

The team found that, indeed, DIBs do exist in both places, and they are strong, which implies there are many carriers.

In the Milky Way, when researchers find strong DIBs, they tend to find a lot of dust, too. This makes sense, because whenever there's more raw material available to make DIBs carriers, there's also more available to make dust. The team found the same situation in Andromeda, Cordiner says.

Of greater interest in Andromeda was whether the strength of the DIBs was related to the amount of PAHs, which are high on the list of candidates for carriers. The researchers knew going into the study that PAHs are plentiful in Andromeda, as they are in the Milky Way.

"The details of the PAH population seem to be somewhat different in Andromeda, though," says Cami. "This makes it interesting to try and find out exactly what is different."

But after checking to see if the PAH levels were related to DIBs strength, "we didn't find any correlation between the two," Cordiner says. That finding doesn't rule out a connection, but it might shift more attention to chains of carbon atoms or to fullerene compounds.

The carriers are not pure, isolated fullerenes, says Cami, who led the team that first detected fullerenes in space. More likely, "atoms or molecules are either locked up in fullerene cages or attached to the outside surface," he explains. "This might even hold for some of the other proposed molecules. For example, you could think of carbon chains dangling from other molecules or even from dust grains."

One big difference between the Milky Way and Andromeda is the number of massive young stars. The Milky Way has more than Andromeda. Because those young stars generate a lot of UV radiation, the Milky Way's interstellar medium has higher levels of this radiation than Andromeda's does.

More radiation means a harsher environment, so organic molecules should survive better in an environment with less radiation. In that sense, Andromeda should be more favorable for the carriers of DIBs and, in theory, should be able to boast more of them. But Cordiner and his colleagues found that the DIBs in Andromeda were only slightly stronger than those in the Milky Way, implying that Andromeda can only claim slightly more carriers.

The observations in the Triangulum add even more intrigue. There, the researchers found strong DIBs even though this galaxy differs in its metallicity, which is a measure of the availability of ingredients for making stars and planets.

The consistency from galaxy to galaxy is surprising, given how much the conditions are thought to vary among them. "But there are no detailed studies of Andromeda to tell us everything we want to know about conditions there," says Cordiner. "And even less is known about the Triangulum."

"If we're going to understand fully how interstellar chemistry works—how stars and planets form," says Cordiner, "then we need a full understanding of the ingredients they use."

Image below shows Andromeda, one of two distant galaxies where astronomers recently searched for diffuse interstellar bands (DIBs). If DIBs were found when looking in a straight line from Earth to a star in the galaxy, the star is circled. Bigger circles indicate stronger DIBs. An "x" means no DIBs were observed. The colors in the insets correspond to wavelengths of the spectrum: blue for UV, green for visible light, and red for infrared